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ASTROPHYSICAL ANALYSIS OF EARTHQUAKE NEAR KRALJEVO (SERBIA) ON 03 NOVEMBER 2010

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Abstract: Results of previous studies have pointed to a statistically significant relationship between the ionospheric, ie. atmospheric disturbances and earthquakes. Also, numerous previous studies concerning the relationship between the sun's activity and disturbances in the atmosphere have been taken into consideration. Based on these indicators, we tried to determine the possible existence of a causative-effective connection between processes on the sun and the earthquake that occurred on 03 November 2010 near Kraljevo (Serbia). Based on theoretical considerations, a new model is proposed that suggests the occurrence of trigger pulse. The results have shown that at statistically more significant number of samples it would be necessary to determine potential regularity in the changes of the parameters of the interplanetary magnetic field (IMF), that is solar wind components (SW) a few days before and after the occurrence of strong earthquakes.

Key words: earthquake, interplanetary magnetic field, model, Kraljevo (Serbia)

Introduction

Powerful earthquakes, particularly in relation to other regions in the world, are not common in Serbia. However, on 03 November 2010 in the central part of Serbia there was an earthquake of M 5.4 (Figure 1). The location of the epicentre was 43.74 N, 20.69 E, exact time of the earthquake 00:56:54.4 UTC and the depth of earthquake focus 2 km (http://www.emsc-csem.org/Earthquake/earthquake.php?id=196649).

Thereafter, a series of much lower intensity earthquakes occurred until 18 November. Unfortunately two people died, and considerable damage to a large extent hampered the normalization of life in the cold days that were coming. As in many other cases, not only in Serbia, there were no indications that an

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earthquake will happen. That is, we do not know that any of the modern models hinted at the possibility of earth tremors, especially not of such intensity (Hattori, 2004).

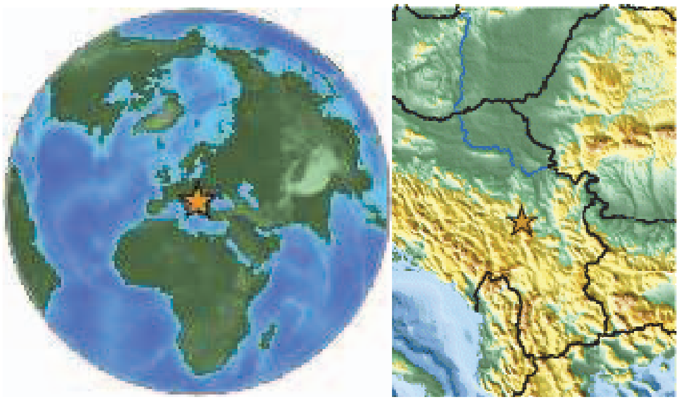

Figure 1. Geographical position of the location of earthquake on 03 November 2010 (http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/usb00009t6/)

In this paper we will try to point to the model that is based on an interactive connection between processes on the sun and the earthquake that occurred near Kraljevo. The basic approach that was implemented during the research referred to causality, ie. time line of events as following: the eruption of energy from the sun in the form of charged particles contained in the electrical IMF, that is SW, magnetization of environment (some parts of the lithosphere) and the occurrence of earthquake.

Theoretical Background

After examining the literature, it turned out that there are numerous studies that indicate a potential connection between processes on the sun and earthquakes in some parts of our planet. Simpson (1967/68) points out that the maximum frequency of earthquakes occurs in the period of moderately high and fluctuating solar activity. Weiyu, Xiudeng, Baohua and Hangcai (2006) conclude that at earthquake in Indonesia on 26 December 2004: 1) data on air temperature can clearly reflect a heat sign and complete process of earthquake energy accumulation and release, 2) an additional structure stress of astro-tidal triggering is an important external factor in the triggering of an earthquake and 3) analyzing more than 40 cases, the results show that for about 60% of strong earthquakes, abnormal air temperature increase and its spatial-time rule are evident. Athanasiou, Anagnostopoulos, Iliopoulos, Pavlos, and David (2011) argue that changes in the energy of ultra low frequency (ULF) electromagnetic waves of Ez electric field component clearly show a connection with the earthquake in Haiti on 12 January 2010. Silva et al. (2011) came to similar conclusions in the case of an earthquake in Portugal in 2010. Mukherjee and Kortvelyessy (2006) point out that along with the sun, interstellar winds may affect the earth tremor, that is, in case they considered, the clouds of hot helium with a much higher density of particles than is common at SW. Seemingly incompatible occurrences at sun-circulation processes in the atmosphere-earthquakes relation are statistically tested by Odintsov, Boyarchuk, Georgieva, Kirov and Atanasov (2006) (Figure 2).

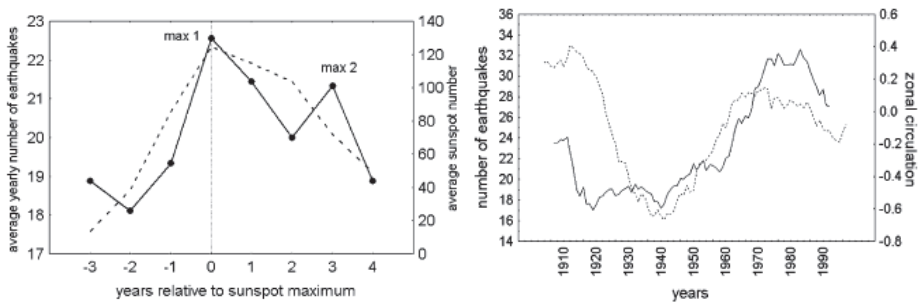

Figure 2. Average number of earthquakes (solid line) and solar activity (dotted line) in the eleven-year solar cycle for the period 1900-1999 - left chart and annual number of earthquakes M ≥ 7 in the period 1900-1997 (solid line) and intensity of zonal circulation (dotted line) in the same period - right chart (Odintsov et al., 2006)

Analyzing the obtained results, the authors of the mentioned paper concluded that the scenario of the solar activity influence on the seismic activity could include the following elements:

– oncoming shock of pressure pulse associated with high speed SW streams or coronar mass ejections compress the magnetosphere,
– the auroral electrojet strengthens,
– the generated atmospheric gravity waves are transmitted downwards,
– westward zonal winds strengthen,
– surface air pressure changes,
– the pressure balance on tectonic plates is diserupted and
– if enough tension is accumulated, an earthquake is triggered.

Radovanović, Stevančević and Štrbac (2003) consider that the strengthening of aurora in polar areas is a supporting optical manifestation of the IMF connection with geomagnetic field. Gomes and Radovanović (2008), Mukherjee (2008), Nikolić, Radovanović and Milijašević (2010), Mukherjee and Radovanović

(2011) and many others point out numerous examples of the SW influence on atmospheric processes, as well as certain aspects of the environment. Gabis and Troshichev (2000) concluded that the impact of short-term changes in solar activity on baric (pressure) field perturbations is evident in the stratosphere (30 mb-level). The meridional perturbations in the stratosphere in case of the Forbush decreases and solar proton events start to develop well before the key date following growth of the UV irradiance typical of the short-term changes in solar activity. Decay of the meridional transfer occurs after the key date evidently under the influence of solar energetic corpuscular flux. Fluctuations of baric field within periods of 5 ± 10 days are typical of meridional and zonal transfer in the troposphere (500 mbar-level), intensities of meridional and zonal transfer being fluctuated in opposite phase. Effect of the key date is not prominent in these fluctuations. Vorticity area Index, characterizing cyclonic activity in the troposphere, shows the striking correspondence to changes of the meridional transfer in the stratosphere. O. Singh, Chauhan, V. Singh and B. Singh (2009) emphasize the strong statistical correlation between ionospheric perturbations and earthquakes. Yonaiguchi and Hayakawa (2007) observed certain regularities in atmospheric perturbations and the occurrence of earthquakes throughout some parts of the year, emphasizing that their analysis still referred to the data for one (2005) year. Hasbi, Mohd Ali and Misran (2011) concluded that in the case of four strong earthquakes in Sumatra, in the period 2004-2007, their results supported the fact that the anomalous upward seismogenic electric field interacts with the eastward electric field and induces the ionospheric anomalies in the near epicenter region as well as the equatorial anomaly shape distortion. The concentrations of electrons show positive and negative anomalies of a few hours to 6 days before the occurrence of earthquake.

Having disclosed in mind, we tried to determine the possible causative-effective relationship between the inflow of energy from the sun and the earthquake near Kraljevo. In this sense, from a theoretical point of view a new model is proposed which, if justified, should be the basis for making predictions.

Heliocentric Electromagnetic Model of an Erthquake Occurrence near Kraljevo

Let us assume that the IMF is a foreign field which acts on a lithospheric environment. If the interplanetary field intensity (H) and magnetic induction (B) are schematically represented (Figure 3), then we can say that with the increase of the IMF intensity, from point O to point A, magnetization in the observed environment will start to increase. The curve from point O to point A can be called the original magnetization curve.

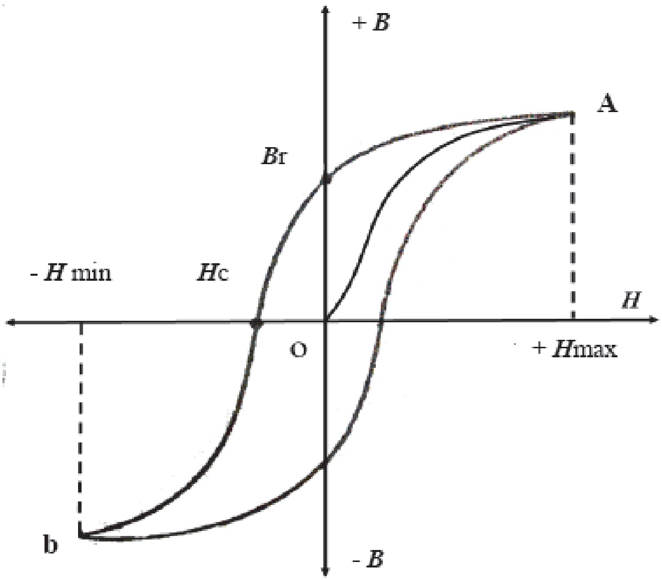

Figure 3. Schematic representation of hysteresis cycle

It comes to saturation at point A, and IMF reaches a maximum value **Hmax**. When the IMF intensity decreases, the magnetic induction **B** will also decrease from point A to Br. When the IMF intensity is equal to zero, the magnetic induction does not vanish, but retains some value which is the remanent induction **Br**. When changing direction of the IMF **H,** the magnetic induction **B** will decrease and at a certain point it will be zero. This point will be marked with **Hc** and called the coercive field or coercive force. For an earthquake to occur, it is necessary for the IMF to change direction, and the magnetic induction **B**r to be equal to zero, that is, to change direction from the positive value + **Br** to **-Br**. The moment of reaching the value of **Hc** is actually a moment of occurrence of earthquake. When the intensity of the IMF reaches **–Hmin,** the maximum negative value of magnetic induction is obtained at point b. If the IMF intensity changes again from -**Hmax** to +**Hmax** and again to –**Hmax,** a hysteresis cycle is obtained for the observed environment. It follows that the size of hysteresis cycle depends on the intensity of the IMF and magnetic characteristics of the environment that is magnetized.

If we assume that between magnetic induction and the IMF intensity is linear dependence **B** = μ**H**, then we get that:

$$d\mathrm{Wm} / \mathrm{dV} = \mu \int_0^{\mathrm{H}} \mathrm{H} d\mathbf{H} = (\mu / 2)\mathbf{H}^2$$ from which it follows that

$$d\mathrm{Wm} / \mathrm{dV} = \tfrac{1}{2} \mathbf{BH}^2$$

B is magnetic induction, **H** – intensity of the magnetic field, μ - permeability of environment and W - energy.

The total energy consumed during the magnetization of environment is:

$$\mathrm{Wm} = \tfrac{1}{2} \int_v \mathbf{BH}\, d\mathrm{V}$$

Mathematical expression which could describe the energy that some environment absorbs during magnetization would be:

$$d\mathrm{Wm} / d\mathrm{V} = \oint \mathbf{B} d\mathbf{H}$$

In situations when **H** and d**B** are of the same sign, the energy density **H***d***B** is positive, that is, an environment that is magnetized absorbs the IMF energy. If **H** and *d***B** are of different signs, an environment that is magnetized releases energy. This practically means that the fault between the two tectonic plates acts as a magnetic energy accumulator. From this we can conclude that the product **B** and the absolute values |**H**| for the observed environment greater, the earthquake more powerful (Stevančević, 2011).

Let us suppose that the fault between the two tectonic plates is affected by one of the components of IMF, which is perpendicular to the fault line. Palamara and Bryant (2004) also wrote about the possibility that charged particles reach the ground, stressing that the key question is how solar/geomagnetic activity joins the lower part of the atmosphere. According to Gomes, Radovanović, Ducić, Milenković and Stevančević (2009) this process takes place in two ways: by the reconnection (in polar regions) and the penetration of the SW particles in the areas of the weakest geomagnetic field, ie. geomagnetic anomalies. One of the main conditions is reduced cloudiness, that is, reduced moisture in the zone of propagation, which acts absorbing on the charged particles. After opening the electric field, due to friction with the more dense layers of the atmosphere, dispersing of protons takes place on the left and electrons on the right (Figure 4) in relation to the main direction of the SW penetration (Radovanović, 2010).

Field intensity **H** and magnetic induction **B** in the tectonic plates that are magnetized have opposite directions. **H** and **B** have the same directions in the fault.

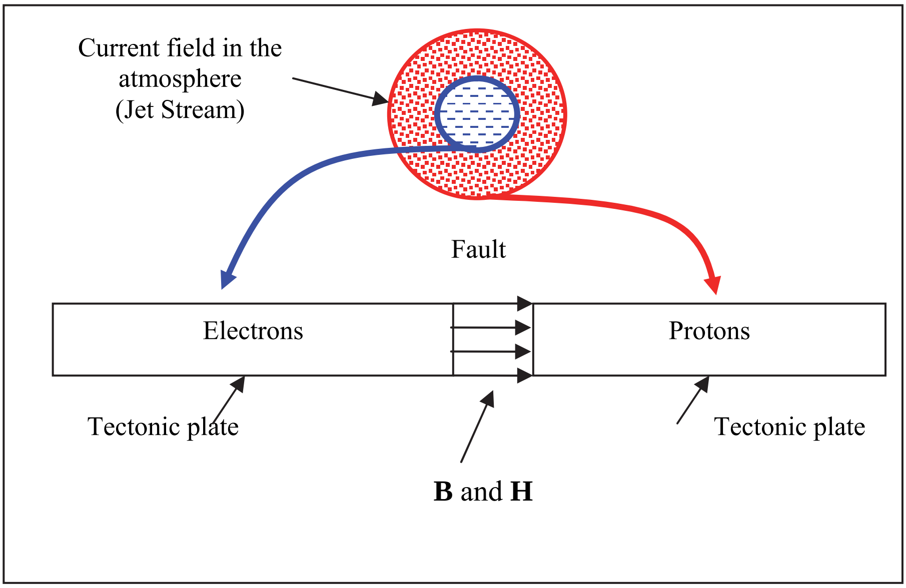

Figure 4. Schematic representation of the magnetization of tectonic plates by the SW charged particles

In the previous figure the current field is marked as Jet Stream because the previous analyses showed that satellite images at altitudes of 250 mb usually adequately reflect the process of the hydrodynamic air mass seizing. Heliocentric hypothesis about the origin of earthquakes is based on the assumption that the first phase requires the influx of protons and electrons to certain lithospheric (tectonic) environments between which a fault is located. Magnetization of environment can practically have an unlimited period of time, because at one point there is a saturation of energy (point A in the Figure 3). When the acting of IMF is over, there will be the so called silent degradation, that is, gradual release of energy occurs, i.e. Demagnetization. From the aspect of theory, the process of energy release is followed by two typical scenarios. The first refers to the gradual degradation to point Hc when the trigger pulse occurs. The time period that includes demagnetization from point A to point Hc depends exclusively on the geological characteristics of the local environment. It follows that if the induction of energy was relatively weak, an earthquake had to be weak under such conditions. In the second case, again there are two different processes. The first refers to a new influx of IMF. It depends on its characteristics whether an earthquake will occur or not. In certain cases it may happen for example that energy is restored again from point Br to point A. In such conditions, local environment can again reach the values of maximal magnetization. In contrast, the characteristics of IMF can be such as to accelerate the process of demagnetization, i.e. to put demagnetization rapidly down from point Br to the value Hc.

Based on analysis of hundreds of strong earthquakes that occurred in 2010 and early 2011, the preliminary results indicate that in the very fault, upon the occurrence of earthquake, magnetic flux can have a crucial role. Okubo, Takeuchi, Utsugi, Yumoto and Sasai Y. (2011) have also emphasized the need for better knowledge of changes in the magnetic field caused during earthquake.

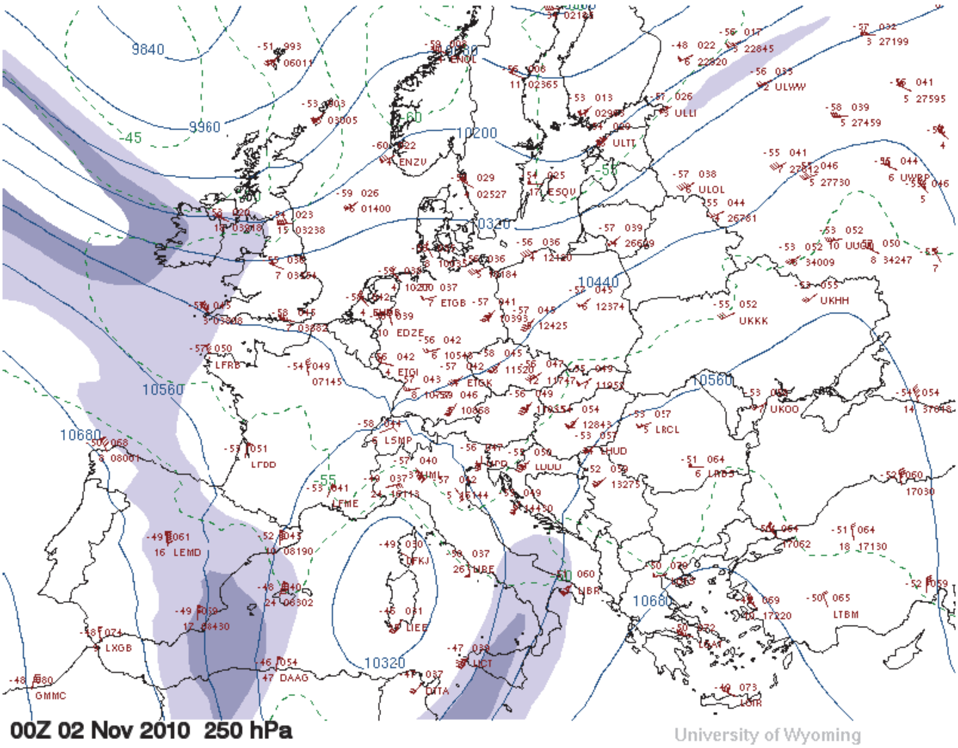

Figure 5. Current field over the Western Europe one day before the occurrence of earthquake near Kraljevo (http://weather.uwyo.edu/upperair/uamap.html)

In the case of the earthquake near Kraljevo, the movement of air masses from west-southwest direction towards the Balkan Peninsula had been noticed one day before the earthquake occurred (Figure 5). Therefore, according to the mentioned heliocentric hypothesis, it was necessary to have protons and electrons induced in the ground north and south of the Morava River during the previous days. The river stretches in the west-east direction and flows through Kraljevo. It can be seen in the Figure 5 that the movement of the current field at 250 mb surface is directed towards the central Balkans. Therefore, the criterion is satisfied that one of the SW components is directed at approximately right angle to the direction of the fault.

The Figure 6 points to the charged particles penetration not only horizontally, but also vertically. Based on that image, we see that the speed of movement of air masses to the central Balkans was reaching 70 knots (approximately 35 m/s). We will not go into matters relating to the connection between processes on the sun and the hydrodynamic seizing of air masses (Stevančević, 2004). It has already been discussed in the introduction that many authors, using different methods, come to the conclusion that it is exactly what occurs, from the zonal circulation to the strongest forms of cyclonic motions.

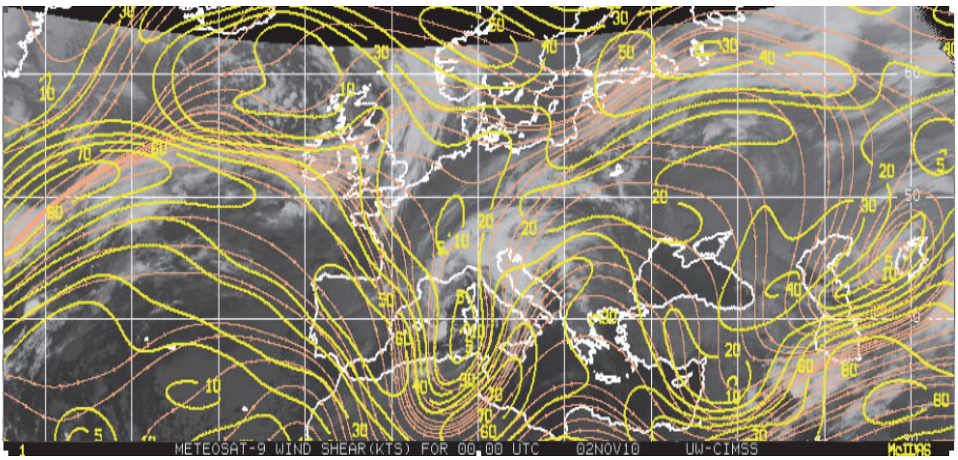

Figure 6. Geographic distribution of mean wind speed 150-300mb level minus 700-925mb level over Europe on 02 November 2010 (http://tropic.ssec.wisc.edu/real-time/windgridmain.php?&basin=europe&sat=wm7)

Perceiving the distribution of wind speed in the previous image (Figure 6), it can be seen that a jet that is associated with the earthquake in Serbia is an integral part of the distribution of wind speed over a wider area, which is provided in the form of waves through the middle and eastern Atlantic, the arc bends to the south, i.e. Mediterranean, and then again as a wave turns to the northeast.

One of the main segments of the heliocentric model of earthquake occurrence is the analysis of x, y, and z components of the SW. As far as we know, they are now for the first time introduced into the scientific understanding of the genesis of earthquakes. Unlike Korepanov, Hayakawa, Yampolski and Lizunov (2009) who in the focus of the research put the issue "from below", at the lithosphere-atmosphere-ionosphere-magnetosphere relation, for this model it could be said that the key parameters are set the other way around. That is, the genesis of earthquakes is observed as a result of the influx and the transformation of energy that comes from "above". Based on the table of mean hour values of IMF, a diagram is drawn (Figure 7).

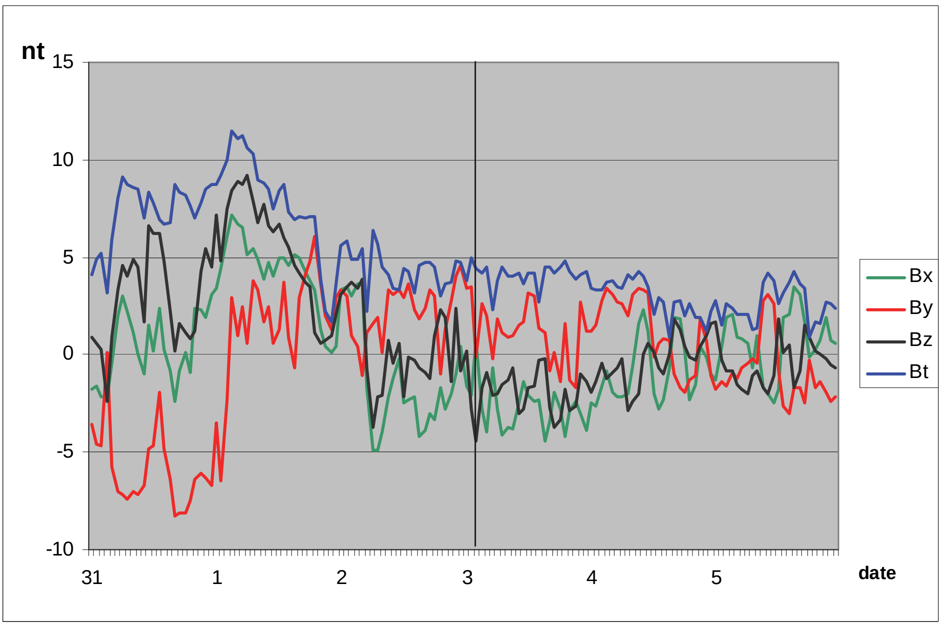

Figure 7. The SW components few days before and after the earthquake near Kraljevo (http://www.swpc.noaa.gov/ftpdir/lists/ace2/201011_ace_mag_1h.txt)

By the SW components analysis, it can be seen that during the 31st October it came to their maximal "decoupling". It is actually the most intensive period of regional magnetization of the lithosphere. It can be seen from the Figure 8 that the influx of energy really occurred that day. The graph was obtained in a similar manner as for the previous figure by taking tabular data of the mean hour values of differential flux of protons.

The moment of the earthquake phenomenon (represented by vertical line in the Figure 7) coincides with a change of direction of Bx in relation to the Bz component. At the time of maximum decoupling, these two components had the same direction of movement. The earthquake had occurred just before the changing of direction of their movement. It can be seen in the Figure 9 that the density of the SW particles sharply increased from the midnight (in UTC) of the 3rd November 2010, reaching a maximum in a relatively short period of time. Simply put, it is hard to ignore the fact that the very moment of the maximum density of the SW particles occurred at or just before the occurrence of earthquake near Kraljevo.

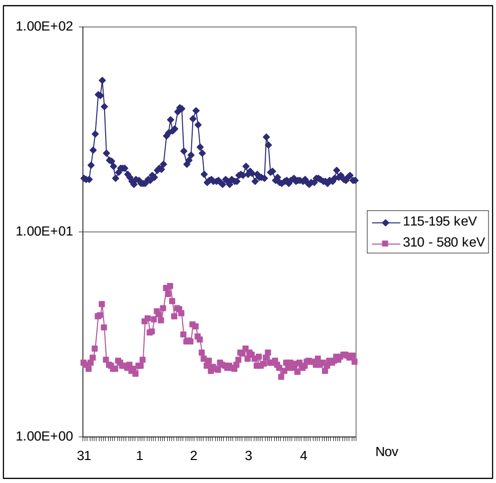

Figure 8 Arrival of electricity to the earth in the range 115-195 and 310-580 keV in late October and early November 2010 (http://www.swpc.noaa.gov/ftpdir/lists/ace2/201010_ace_epam_1h.txt)

It appears that the earthquake near Kraljevo should actually happen at the end of the 4th or early 5th November 2010 when a "compression" of the SW components would occur. That means that the gradual demagnetization would bring closer together the values of x, y and z components to the critical point. According to the model shown in Figure 3, the achievement of coercive force Hc could be expected. However, as can be seen in the Figure 9, in the meantime a sudden influx of IMF (Figures 5 and 6) occurred, accelerating the bringing of magnetic induction **B** to the value of coercive force, that is, the occurrence of earthquake, by which the process of trigger pulse was actually accelerated.

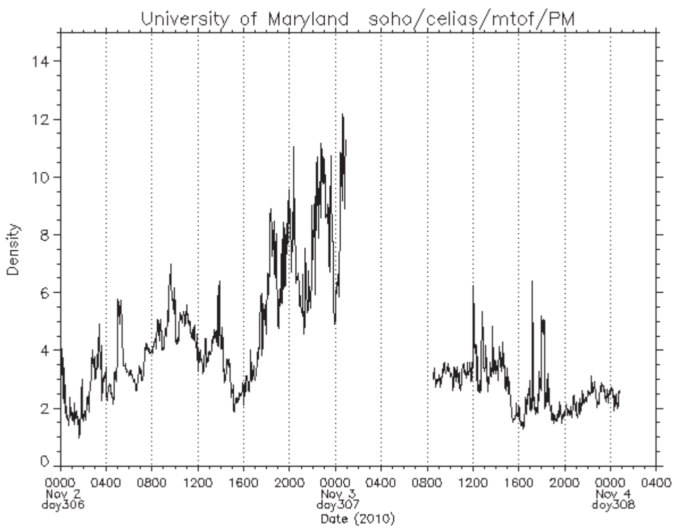

Figure 9 Density of the SW particles one day before the earthquake, on the day of the earthquake and one day after the earthquake in Kraljevo (http://umtof.umd.edu/pm)

Following the mindset, it would be real to expect that the geomagnetic activity had to "react" to the energy pulse coming from outside. The previous figure shows that between 01:00 and 02:00 am on the 3rd of November there has been a sharp drop in H component of the geomagnetic field. This brings us to yet another indicator that supports the presented hypothesis.

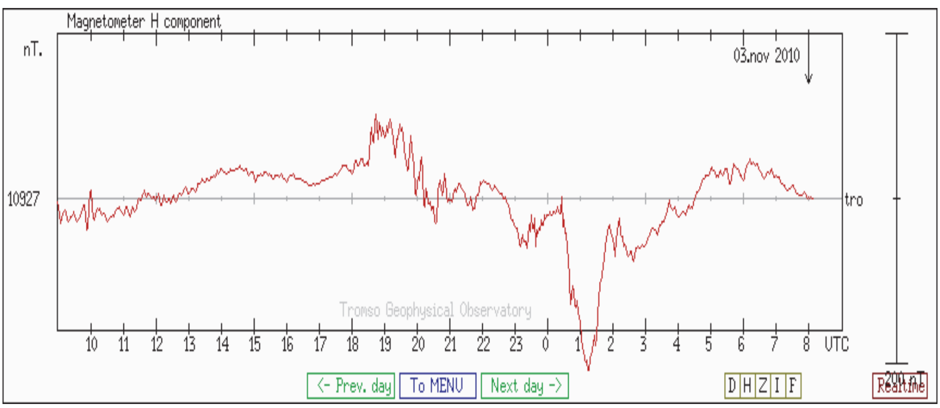

Figure 10 H component of geomagnetic field at the end of the 2nd and early 3rd November 2010 (http://flux.phys.uit.no/stackplot/)

If presented considerations are correct, then it appears that the absence of subsequent influx of IMF would not actually lead to the emergence of such strong earthquake. In other words, gradual demagnetization, which should result in an earthquake on 04/05. November 2010, probably would not have caused such a strong earthquake, as was the case two days earlier. It could be argued that if an earthquake had occurred, it would have probably be a weaker shake without serious consequences for the local population.

Conclusion

The presented results may form the basis for the heliocentric hypothesis about the genesis of earthquakes. The base in question should be aimed at the creation of prognostic models. However, the elaboration of this approach opens many new questions, among which the following ones should be noted:

– in which way, through the presented approach, the earthquake focuses can be seen, located at depths of several hundred kilometers,
– what is the relation of relatively weak tremors following the powerful earthquakes,
– whether the proposed model can explain the geographical regularities of locations of the earthquakes that occurred on the same day in different parts of our planet,
– if the above approach is justified, what is the function of the occurrence of strong earthquakes in relation to the solar cycle,
– bearing in mind the principle difference between the cosmic and solar radiation, whether the occurrence of an earthquake can be caused by energies originating outside the solar system.

At this point, it appears that the elaboration of the results requires multidisciplinary research, as well as analysis of a number of strong earthquakes. Their systematization based on heliocentric principles can provide the basis for answers to questions, as well as a new approach for developing prognostic models.

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References

Athanasiou, M. A., Anagnostopoulos, G. C., Iliopoulos, A. C., Pavlos, G. P. & David, C. N. (2011). Enhanced ULF radiation observed by DEMETER two months around the strong 2010 Haiti earthquake. *Natural Hazards and Earth System Sciences*, *11*, 1091–1098, doi:10.5194/nhess-11-1091-2011.

Gabis, I. P. & Troshichev, O. A. (2000). Influence of short-term changes in solar activity on baric field perturbations in the stratosphere and troposphere. *Journal of Atmospheric and Solar-Terrestrial Physics, 62*, 725-735.

Gomes, J. F. P. & Radovanovic, M. (2008). Solar activity as a possible cause of large forest fires - a case study: Analysis of the Portuguese forest fires. *Science of the total environment*, *394*(1), 197 – 205, doi:10.1016/j.scitotenv.2008.01.040, ISSN 0048-9697.

Gomes, J. F. P, Radovanović, M., Ducić, V., Milenković M. & Stevančević, M. (2009). Wildfire in Deliblatska Pescara (Serbia) – Case Analysis on July 24th 2007. In: *Forest Fires: Detection, Suppression and Prevention* (pp. 89-140). New York, NY: Nova Science Publishers.

Hasbi A. M., Mohd Ali M A. & Misran, N. (2011). Ionospheric variations before some large earthquakes over Sumatra. *Natural Hazards and Earth System Sciences*, *11*, 597–611, doi:10.5194/nhess-11-597-2011.

Hattori, K. (2004). ULF Geomagnetic Changes Associated with Large Earthquakes. *TAO*, *15*(3), 329-360.

Korepanov, V., Hayakawa, M., Yampolski, Y. & Lizunov, G. (2009). AGW as a seismo-ionospheric coupling responsible agent. *Physics and Chemistry of the Earth*, *34*, 485–495, doi:10.1016/j.pce.2008.07.014.

Mukherjee, S., & Kortvelyessy, L. (2006). Starstorm influence on earth leads tsunami and earthquakes. In *Earthquake Prediction*, (pp. 69-76), Brill, Leiden-Boston.

Mukherjee, S. (2008). Cosmic Influence on the Sun-Earth Environment. *Sensors, 8*, 7736-7752, DOI: 10.3390/s8127736.

Mukherjee, S., &Radovanović, M. (2011). Influence of the Sun in the Genesis of Tornadoes. *The IUP Journal of Earth Sciences*, *5*(1), 7-21.

Nikolić, J., Radovanović, M., & Milijašević, D. (2010). An Astrophysical Analysis of Weather Based on the Solar Wind Parameters. *Nuclear Technology & Radiation Protection, 25*(3), 171-178. DOI: 10.2298/NTRP1003171N.

Odintsov, S., Boyarchuk, K., Georgieva, K., Kirov, B., & Atanasov, D. (2006). Long-period trends in global seismic and geomagnetic activity and their relation to solar activity. *Physics and Chemistry of the Earth, 31*, 88–93, doi:10.1016/j.pce.2005.03.004.

Okubo, K., Takeuchi, N., Utsugi, M., Yumoto, K. & Sasai, Y. (2011). Direct magnetic signals from earthquake rupturing: Iwate-Miyagi earthquake of M 7.2, Japan. *Earth and Planetary Science Letters, 305*, 65–72, doi:10.1016/j.epsl.2011.02.042.

Palamara, R. D., & Bryant, A. E. (2004). Geomagnetic activity forcing of the Northern Annular Mode via the stratosphere. *Annales Geophysicae, 22*, 725-731.

Radovanović, M., Stevančević, M. & Štrbac, D. (2003). A Contibution to the Study of the Influence of the Energy of Solar Wind upon the Atmospheric Processes. *Journal of the Geographical Institute „Jovan Cvijić" SASA*, 1–18.

Radovanović, M. (2010). Forest fires in Europe from July 22nd to 25th 2009. *Archives of Biological Sciences, 62*(2), 419-424, DOI:10.2298/ABS1002419R.

Silva, H. G., Bezzeghoud, M., Reis, A. H., Rosa, R. N., Tlemcani, M., Araujo, A.A., … Biagi, P.F. (2011). Atmospheric electrical field decrease during the M = 4.1 Sousel earthquake (Portugal). *Natural Hazards and Earth System Sciences, 11*, 987–991, doi:10.5194/nhess-11-987-2011.

Simpson, J. F. (1967-1968). Solar activity as a triggering mechanism for earthquakes. *Earth and Planetary Science Letters, 3*, 417-425, doi:10.1016/0012-821X(67)90071-4.

Singh, O. P., Chauhan, V., Singh, V. & Singh, B. (2009). Anomalous variation in total electron content (TEC) associated with earthquakes in India during September 2006–November 2007. *Physics and Chemistry of the Earth, 34*, 479–484, doi:10.1016/j.pce.2008.07.012.

Stevančević, M. (2004). *Secrets of the Solar Wind (Tajne Sunčevog vetra*), Belgrade.

Stevančević, M. (2011). *Theoretic Elements of Helocentric Electromagnetic Seismology*. Belgrade School of Meteorology, vol. IV, pp.79-310, Belgrade.

Weiyu, M., Xiudeng, X., Baohua, X. & Hangcai, Z. (2006). Abnormal temperature increase and astro-tidal triggering in the tsunami earthquake in Indonesiqa magnitude 9.0. *In Earthquake Prediction*, (pp. 61-68). Brill, Leiden-Boston.

Yonaiguchi, N., Ida, Y. & Hayakawa, M. (2007). On the statistical correlation of over-horizon VHF signals with meteorological radio ducting and seismicity. *Journal of Atmospheric and Solar-Terrestrial Physics, 69*, 661–674, doi:10.1016/j.jastp.2007.01.007.